Directed flow as a phase transition signal in relativistic heavy ion collisions *

J. Steinheimer[1,2], *J. Auvinen*[†1], *H. Petersen*[1,2,3], *M. Bleicher*[1,2], *and H. Stöcker*[1,2,3]

[1]Frankfurt Institute for Advanced Studies, Frankfurt, Germany; [2]Institut für Theoretische Physik, Goethe Universität Frankfurt, Frankfurt, Germany; [3]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany

Recent STAR data [1] from the RHIC beam energy scan show that the slope of the net-proton directed flow v_1 near midrapidity $y = 0$ changes sign twice within the collision energy range $\sqrt{s_{NN}}$ = 7.7 - 39 GeV, which has been predicted by the earlier fluid calculations to be a signal of a first-order phase transition between hadronic matter and quark-gluon plasma. We study this phenomenon utilizing a hybrid model where the non-equilibrium phases at the beginning and in the end of a heavy-ion collision are described by the UrQMD transport model, while the intermediate hot and dense stage is modeled with (3+1)-D ideal hydrodynamics. In [2] we examine the sensitivity of the directed flow v_1 to the order of the phase transition by comparing simulations with a first-order phase transition "Bag model" equation of state (EoS) to calculations with a chiral model EoS, which has a cross-over phase transition.

First, to emulate the earlier fluid calculations, we initialize the cold matter of two colliding nuclei as two distributions of energy and baryon density. The UrQMD model is still utilized for the final hadron gas phase. Figures 1a and 1b show the difference in dv_1/dy between the two equations of state for Au+Au collisions at impact parameter b = 8 fm. While the predicted minimum in dv_1/dy with a first-order phase transition is observed when using isochronous hypersurface for the transition from hydrodynamics to transport (Fig. 1a), the difference between the two equations of state is considerably smaller when using iso-energy density condition for fluid to particle transition (Fig. 1b).

Figure 1c shows the energy dependence of the proton and antiproton v_1 slope at midrapidity, obtained from the full hybrid simulation with the initial non-equilibrium transport phase. The directed flow was calculated using events with impact parameter $b = 4.6 - 9.4$ fm, which approximates the $(10 - 40)\%$ centrality range of the STAR data. The two EoS are completely indistinguishable in the hybrid simulations, questioning the usability of v_1 as a signal of the first-order phase transition. However, the hybrid model results also deviate notably from experimental data, which makes further studies on the topic necessary.

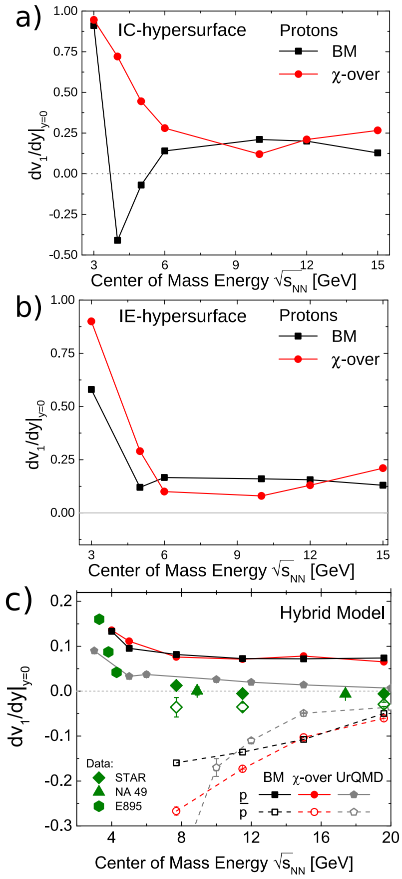

Figure 1: a) and b) Slope of proton v_1 at midrapidity $|y| < 0.5$, calculated for an equation of state with first-order phase transition (black) and cross-over phase transition (red) for isochronous fluid-to-particles transition hypersurface (a) and iso-energy density hypersurface (b) for Au+Au collisions at impact parameter b = 8 fm. c) v_1 slope at midrapidity for protons (solid symbols) and anti-protons (open symbols) for impact parameter range $b = 4.6 - 9.4$ fm, extracted from the hybrid model calculations with a first order (black) and crossover EoS (red). Results are compared with the UrQMD model calculations (grey) and experimental data from STAR, NA49 and E895 collaborations (green). Originally published in [2].

References

[1] L. Adamczyk et al. [STAR Collaboration], "Beam-Energy Dependence of the Directed Flow of Protons, Antiprotons, and Pions in Au+Au Collisions", Phys. Rev. Lett. 112 (2014) 162301

[2] J. Steinheimer, J. Auvinen, H. Petersen, M. Bleicher, H. Stöcker, "Examination of directed flow as a signal for a phase transition in relativistic nuclear collisions", Phys. Rev. C 89 (2014) 054913

* Work supported by HIC for FAIR and Helmholtz-Nachwuchsgruppe VH-NG-822. Computational resources have been provided by the Center for Scientific Computing (CSC) at Goethe Universität Frankfurt.

† auvinen@fias.uni-frankfurt.de

DOI:10.15120/GR-2015-1-MU-THEORY-25